Application of the Real Options Theory to Investment Appraisal: The Case of a Photovoltaic Investment

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Abstract

Wrong investment decisions today can lead to situations in the future that will be unsustainable and lead eventually to the bankruptcy of enterprises. Therefore, good financial management combined with good capital investment decision-making are critical to the survival and long-term success of the firms. Traditionally, the discounted cash flow (DCF) methods (e.g. NPV – Net Present Value and IRR – Internal Rate of Return) have been worldwide used to evaluate project investments. However, given that today investments are characterized by high risks and uncertainty, DCF methodologies might be inadequate to deal with these issues. Some authors argue that only the techniques that can appropriately address the problem of uncertainty should be applied. In this paper, the major differences between the traditional methods and Real Options Theory (ROT) were analysed, in the context of an investment in the energy sector. Energy shortage, global warming, and climate change led to an increase in the use of alternative sources of energy, with renewable energy sources (RES) playing a fundamental role in this new energetic paradigm. However, the investment costs often constitute a major barrier to their spread use. Moreover, the overall benefits of renewable energy technologies are often not well understood and consequently they are often evaluated to be not as cost effective as traditional technologies. The way investors evaluate their investments call now for the use of more sophisticated evaluation techniques. Real Options approach can deal with these issues and, as so, began to be considered and applied for the energy sector decision aid. A large set of applications in almost all fields of energy decision making, from electricity generation, technologies appraisal and to policy evaluation is available in the literature. However the use of this technique in the field of RES is still limited and worth to be analysed. This paper addresses this issue. A review of the current state of the art in the application of Real Options approach to investments in non-renewable energy sources and RES is presented, giving perspectives for further research in this field. Also, an application of the ROT to a photovoltaic investment with the study of three different cases is presented, providing some interest conclusions about the major differences in evaluating this technology under ROT and the traditional project evaluation techniques.

Keywords: Project Evaluation Traditional Techniques, Real Options Theory, Renewable Energy Sources, Energy Sector, Learning Curves

Resumo

Más decisões de investimento hoje podem levar a situações insustentáveis no futuro e que, eventualmente poderão levar à falência de empresas. Portanto, uma boa gestão financeira combinada com uma correcta tomada de decisão de investimento são fundamentais para a sobrevivência e sucesso a longo prazo das empresas. Tradicionalmente, métodos baseados nos Fluxos de Caixa Actualizados (*Cash flows*) (e.g. VAL – Valor Actual Líquido e TIR – Taxa Interna de Rentabilidade) têm sido utilizados para avaliar os projectos de investimento. Porém, os investimentos de hoje são caracterizados por elevados níveis de risco e incerteza, pelo que metodologias como o VAL são inadequadas para lidar completamente com essas questões. Alguns autores argumentam que somente as técnicas que conseguem abordar adequadamente o problema da incerteza devem ser aplicadas. Neste trabalho, as principais diferenças entre os métodos tradicionais e a Teoria das Opções Reais (TOR) foram analisadas, no contexto de um investimento no sector da energia. A escassez de energia, aquecimento global e alterações climáticas levaram a um aumento no uso de fontes alternativas de energia, com as fontes de energia renováveis a desempenharem um papel fundamental neste novo paradigma energético. No entanto, os custos de investimento constituem, muitas vezes, um grande obstáculo ao seu uso e à sua difusão. Para além disso, os benefícios globais das tecnologias de energias renováveis são frequentemente mal compreendidos e por isso estas são frequentemente avaliadas como sendo menos rentáveis do que as tecnologias tradicionais. A forma como os investidores avaliam o potencial dos seus investimentos parece indicar a necessidade do uso de técnicas de avaliação mais sofisticadas. A Teoria das Opções Reais consegue lidar com estas questões e, como tal, começou a ser aplicada no apoio à tomada de decisão no sector energético. Um grande conjunto de aplicações em quase todos os domínios da tomada de decisão neste sector, desde a avaliação de tecnologias de geração de electricidade até à avaliação das políticas, pode ser encontrado na literatura. No entanto, o uso desta técnica no domínio da avaliação de projectos de investimento em energias renováveis é ainda limitado e vale a pena ser analisado. Este trabalho aborda esta questão. Assim, apresenta-se uma revisão do estado da arte na aplicação da metodologia das opções reais para investimentos em fontes de energia não renovável e renovável, sugerindo-se perspectivas para futuras

pesquisas neste campo. Além disso, ilustra-se a aplicação da teoria das Opções Reais a um investimento num parque fotovoltaico, fornecendo algumas conclusões interessantes sobre as principais diferenças entre a avaliação desta tecnologia pela teoria das Opões Reais e pelas técnicas tradicionais de avaliação de projectos de investimento.

Palavras-chave: Técnicas Tradicionais de Avaliação de Projectos, Opções Reais, Energias Renováveis, Sector energético, Curvas de Aprendizagem

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Abbreviations and Nomenclature

ARR – Accounting Rate of Return

CF – Cash Flow

DCF – Discounted Cash Flow

EU ETS - European Union Emission allowance Trading Scheme

GBM – Geometric Brownian motion

GDP – Gross Domestic Product

IEA - International Energy Agency

IRR – Internal Rate of Return

LC - Learning curves

LR - Learning Ratio

NPV – Net Present Value

O&M - Operations and Maintenance

PP – Payback Period

PPA - Power Purchase Agreement

PR - Progress Ratio

PV - Photovoltaic

RES – Renewable Energy Sources

RET – Renewable Energy Technology

ROI – Return on Investment

ROT – Real Option Theory

1. Introduction

1.1. Scope

Good financial management coupled with the right decision regarding investment projects to undertake are crucial to the survival and long-term success of companies (Bennouna et al., 2010). In fact, managers should implement investment projects only if that investments increase the value of the company, which means that managers should identify and carry out all projects that add value to the company in order to maximize the wealth of its owners (Gilbert, 2005, Ryan and Ryan, 2002).

Project Evaluation is one of the major decision areas with which the contemporary manager is confronted and it is a particularly important task since the future of the company depends on the success of the implemented projects (Remer and Nieto, 1995a). Project evaluation methods are tools for investment decision making and have been defined in literature as the methods and techniques used to evaluate and select an investment project (Verbeeten, 2006).

Thus, whoever wants to invest need useful tools to predict the profitability of the proposed investment. To this end, there are several methods and techniques to help the investor to make an economically wise decision. It should be noted that none evaluation method can tell the investor, surely, to invest or not. Investment appraisal methods are based on estimates and forecasts about the future performance of projects. As such, it is associated with a series of errors, since the future is always uncertain. Thus, any technique used to evaluate the investment project can only give an indication, serving as a guide to the investor, based on those forecasts. Ultimately, is the investor who must make the decision, that is, if he chooses to take the risk or not.

An investment can be defined as the act of incurring in a cost in the present, in anticipation of getting a higher return in the future. Most investment decisions share three important characteristics (Dixit and Pindyck, 1994): a) the investment is partially or totally irreversible, i.e., the initial capital expenditure is, at least, partly a sunk cost; b) there is uncertainty about the returns provided by the actual investment, this is, the best one can do is assign probabilities to different possible outcomes; and c) the promoter of the investment has some freedom to decide the most appropriate time to make the investment, i.e., he may postpone the decision to obtain more information about the future. These three characteristics interact to determine the optimal decision of investors. However, the "traditional" approach (as reflected, for example, in the NPV criterion) has not recognized the quantity and quality of interaction between these three characteristics, (Dixit and Pindyck, 1994). In fact, the NPV rule is based on certain assumptions, to some extent, simplistic. For example, or assume that investment is reversible, or, assuming that it is irreversible, corresponds to an all or nothing decision, i.e., if the company does not implement the investment project, loses the opportunity to do so in the future. Although some investments have these characteristics, most investments have not (Dixit and Pindyck, 1994). That is, the irreversibility and the possibility to choose the best timing to undertake the investment are important characteristics of most investments in reality. Moreover, traditional evaluation methods emphasize the financial return. That is, they tend to consider only tangible aspects, neglecting elements of intangible nature, such as future competitive advantage, future opportunities, or the flexibility of management.

One way of dealing with these aspects (namely, irreversibility, uncertainty and timing of investments) is to develop a similar reasoning to the investment in financial options. This approach is known as Real Options Theory (ROT), (Trigeorgis, 1993).

It can be said that a real option is the flexibility that a manager has to make decisions about real assets (Santos and Pamplona, 2005). As new details emerge and the uncertainties on the cash flow are dying out, managers can make decisions that can positively influence the value of the project (Dixit and Pindyck, 1994). Some examples of decisions with which managers are faced are: What is the right time to invest, to abandon or temporarily stop a project? What is the possibility of modifying the operating characteristics of the project? Or, is there the possibility of exchanging an asset for another? In this sense, an investment project can be seen as a set of real options on a real asset - the project.

1.2. Objectives of the research

The main objective of this research aims to prove how traditional evaluation techniques may fail in the evaluation of engineering projects characterized by high uncertainty and complexity. To do so, it is intended to develop a framework that demonstrates the process of applying Real Options to a photovoltaic investment and then compare the Real Options evaluation with the traditional evaluation.

The main objectives of this research are summarized as follows:

- Description and critical analysis of the major limitations of the traditional methods of project evaluation, based on a review of the literature.
- A literature review on the association between the use of sophisticated project evaluation methods and companies performance
- A literature review on ROT in explaining investment decisions.
- Description of the main applications of the ROT in the context of investment decisions, with a particular emphasis on the energy sector.
- Development of a ROT framework and corresponding application to the Renewable Energy Sources, namely to a photovoltaic case.
- Comparison of the traditional evaluation of the photovoltaic case with the real options approach.

1.3. Organization of the dissertation

During the research, the acquired information was based on primary and secondary sources. Thus, as primary sources theses and reports were used and as secondary sources, books and scientific journals. The objective was to gain an understanding of the problem and of the possible approaches, forming the theoretical basis of the work.

Relatively to the mathematical model, were used the Black-Scholes option pricing model to value the real option. To obtain the financial data, were used some financial mathematical equations and some statistical knowledge.

The work was conducted according to the objectives outlined and it is organised as follows:

Chapter 2 begins with the presentation of the traditional project evaluation techniques, highlighting its major advantages and drawbacks. Also, a brief description of their use by companies and the link between the degree of sophistication of the methods and companies' performance is presented. Afterwards, the ROT is presented, describing its main characteristics, and referring the most common types of real options.

In Chapter 3, a critical literature review about the application of the ROT to the energy sector, in general, and to Renewable Energy Sources, in particular, is presented. In Chapter 4, the usefulness of the RO approach in comparison with the tradition evaluation is illustrated, with an application to a photovoltaic investment. Chapter 5 draws the main conclusions of this work, presenting also some perspectives for further research.

2. Project Evaluation

Nowadays, bad investment decisions can lead to situations in the future that will be unsustainable and lead, eventually, to the bankruptcy of enterprises. Thus, it is crucial that managers use alternative methods to maximize the wealth of stakeholders (Ryan and Ryan, 2002).

Thus, researchers have developed methods in order to better ascertain the decision-making, such as the Net Present Value – NPV, the Internal Rate of Return - IRR and Payback Period – PP, among others. These methods, belonging to what can be called the traditional evaluation, can be classified in two major groups: the sophisticated methods and the unsophisticated methods.

Over the years, the academic community has tried to convince managers that these sophisticated methods exist and can improve the decision making process of the project evaluation, unlike the unsophisticated methods. Many authors have documented a trend in the use of sophisticated methods by companies. However, these studies have not been able to prove that companies with better economic results are more likely to employ sophisticated methods, than companies with lower economic performance (Farragher et al., 2001, Klammer, 1973b, Ryan and Ryan, 2002, Graham and Harvey, 2002)

2.1. Traditional evaluation

In this section some of the most used methods will be described. The first to be shown will be the unsophisticated, followed by the sophisticated methods. The description of each one will contain a definition, its mathematical formula and some advantages and disadvantages of each method.

The major difference between these two groups of methods sums up to the fact that the unsophisticated methods, in contrast to the sophisticated ones, are based in the accounting profit, instead of the concept of cash-flow (Remer and Nieto, 1995a), and/or do not consider the time value of money, i.e. do not discount the cash flows (Menezes, 1988).

2.1.1. Unsophisticated methods

The unsophisticated methods do not consider the time value of money or are based on the use of accounting indicators. Net income are the best known measure of profitability and, therefore, of greater acceptance. However, net income is not an appropriate measure of profitability in evaluating investment projects, simply because they rely on accounting procedures/principles (Barros, 1999).

Though one can find plenty of these methods on the literature, only the most used or well-known are described in which follows[1]:

- Accounting rate of return
- Benefit/Cost ratio
- Payback Period

2.1.1.1. Accounting rate of return

This method falls within a large set of accounting methods, which are primarily accounting concepts of the profitability of an investment project. In this case, it gives the recovery rate of the investment (Remer and Nieto, 1995b).

The accounting rate of return is given by the ratio of the average annual net income and the investment (either initial or average book value of a particular project). Thus, the result of this ratio results in the recovery rate of the investment (Blocher et al., 2002).

This method can be described as follows:

$$ARR = \frac{\text{Average annual net income}}{Investment} \qquad (1)$$

Because of the fact this method uses data generated for financial reports, no special procedures are needed to generate that same data. The cost of generating the data for investment analysis using this method is low in comparison with other methods. It also considers all net proceeds from the life of a project, therefore, delivers results on its profitability (Blocher et al., 2002).

This method also presents an advantage over the Payback Period method, as Accounting Rate of Return includes the entire investment period in the analysis, while the payback period only uses the data to the moment of payback.

It can be pointed out as a disadvantage the fact that this method only use accounting data and that data rely on the chosen accounting procedures. Different procedures can lead to substantially different results.

[1] For a deeper understanding of this issue, see, for example, Remer and Nieto (1995a,b).

2.1.1.2. Benefit/Cost ratio

The Benefit/Cost ratio was introduced primarily as a result of the U.S. Government's need to evaluate project proposals submitted to Congress. In 1930, the Congress established the criteria for acceptance of a project where the benefits of a project must outweigh the costs. In this case, the population receives the benefits while the government incurs the cost. However, in the private sector, the benefits and costs are usually charged and received, respectively, for the same individual or corporation (Remer and Nieto, 1995b)

This method is defined as the ratio between the benefits and costs of a given project:

$$Benefit\ Cost\ ratio\ = \frac{Benefits}{Costs} \tag{2}$$

The main advantage of this method is the ease of calculation as well as the particularity of comparing data that are initially incomparable. For example, sometimes the benefits are not monetary neither do they possess a quantitative value (Remer and Nieto, 1995b).

It is often difficult to identify and quantify all the benefits in monetary values, making it difficult to identify all individuals who are users and / or targets of the project. Also, like the previous method, it does not consider the time value of money.

2.1.1.3. Payback Period

Investors, most often, ask how long it takes to recover the money invested. This method provides the answer. The payback period is an evaluation criterion that computes the period of time the project takes to recover the capital invested. In fact, any investment has an initial period of expenditures followed by a period of net revenues. The time required to the revenues recover the capital expenditure is the payback period (Barros, 2000). In other wors, the payback period of an investment is defined as the required time for all accumulated net revenue equal the investment costs (Blocher et al., 2002).

This method can be described as follows:

$$PP = \frac{I}{\frac{R}{N}} \tag{3}$$

Where,

I – Investment;

R – Sum of operating cash flows;

N – Number of years of investment project.

It is assumed that each year the cash flows are distributed regularly over the years.

This method has the convenience of being easy to calculate, and, in principle, being able to eliminate projects which do not satisfy the defined objectives according to the available amounts to invest (Barros, 1995).

Another advantage is due to the fact that this method is easily understood by people unfamiliar with the economic engineering (Remer and Nieto, 1995b).

Like all the studied methods in this section, this has as main disadvantage the fact that ignores the time value of money (in its original formulation), also ignores the cash flows beyond the payback period (Blocher et al., 2002).

2.1.2. Sophisticated Methods

Sophisticated methods are the methods of project evaluation by excellence. These methods have as main characteristic the incorporation of the time value of money, and being based on the concept of cash flows (Remer and Nieto, 1995a).

The techniques based on the discounted cash-flow evaluate the invested capital taking into account the present value of all future income obtained from the initial investment (Blocher et al., 2002).

As for the unsophisticated method, it will only be presented the most common sophisticated methods, therefore:

- Net Present Value
- Internal Rate of Return
- Return on Investment

2.1.2.1. Net Present Value

The Net Present Value is the valuation method favored by nearly all the manuals for project evaluation, mainly for being the most consistent in the context of project selection (Barros, 2000).

This approach fits perfectly with the objective of maximizing firm value because it allows an analysis of the absolute return of new investment and, simultaneously, the consideration of their effects on cash flow (Menezes, 1988).

The Net Present Value of an investment can be defined as the net present value of future net cash flows after subtracting the initial investment (Menezes, 1988).

This method can be described as follows:

$$NPV = \sum_{t=0}^{n} \frac{CashFlow\ at\ time\ t}{(1+i)^t} \qquad (4)$$

Where,

i – Discount rate;

When the $NPV > 0$, the project should be accepted. If the $NPV < 0$, the project should be rejected. If the NPV=0, the project could be accepted but, since we are dealing with projections about future outcomes, it has to be taken into account some concerns.

NPV greater than 0 means that the project will cover both the initial investment as well as the minimum wage required by the investor, generating even a financial surplus. In other words, the project will return a yield higher than the best alternative investment with an equivalent risk level, since the discount rate reflects the opportunity cost of capital. Thus, since the purpose of the companies' managers is to maximize shareholder wealth, they should undertake all projects that have an $NPV > 0$, or, if two projects are mutually exclusive, should be chosen the one with the highest positive NPV.

As mentioned above, as this method considers the time value of money and is based on cash flows, is seen as an advantage of using this technique (Blocher et al., 2002). Moreover, an advantage of using this method relies on the fact that it exposes the present consequences of a project (Remer and Nieto, 1995b).

As major disadvantages one can find: it is not meaningful to compare projects that require different levels of investment, beyond that it favors large investments (Blocher et al., 2002); in the case of mutually exclusive projects, if they have different life time, the NPV of both alternatives can not be directly compared; and this method is not well understood by people who are not familiar with the Economic Engineering (Remer and Nieto, 1995b).

2.1.2.2. Internal Rate of Return

The Internal Rate of Return is the highest rate that an investor can borrow to finance investment without losing money, or the maximum rate that an investor must pay to avoid losing money (Barros, 1995).

The Internal Rate of Return can be defined as the method that estimates the discount rate, which makes the present value of future net cash flows equal to the initial investment (Blocher et al., 2002). In other words, it is the rate that makes the Net Present Value equal to zero (Barros, 1995).

This method can be described as follows:

$$NPV = \sum_{t=0}^{n} \frac{CashFlow}{(1+IRR)^t} = 0 \qquad (5)$$

Like the previous method, this method presents as advantages the fact that it considers the time value of money, as well as is extremely easy to compare projects with different levels of investment (Blocher et al., 2002).

The fact that only consider internal factors is seen as an advantage by some authors, which is the case of Remer and Nieto (1995b).

The major drawback of this method is that, many times, the rate of return obtained by the application of this method is unrealistic. Also, it can be extremely complex to apply this method manually (Blocher et al., 2002).

2.1.2.3. Return on Investment

The Return on Investment is a profitability index, that is, it gives the actual profitability per unit of capital invested (Barros, 1995).

This method is defined as the ratio between the present value of future cash flows and the investment value (Barros, 1995).

This is a method that has very large similarities with the NPV. However, its usefulness emerges in the context of financial restrictions faced by firms. This method helps to rank different projects according to the NPV obtained per unit of capital invested.

This method can be described as follows:

$$ROI = \frac{\sum_{p=0}^{n} \frac{Cash\ flow_p}{(1+i)^p}}{I} \quad (6)$$

Where,

I – Investment;

The main advantages are similar to the ones of the NPV method, and also suggest a measure of profitability per unit of currency invested (Remer and Nieto, 1995b).

It can be pointed as a disadvantage the amount of calculations that may be required to use this method and also by the slow pace of implementation.

2.2. Application of the previous methods by companies

Project evaluation has been seen as one of the main growth areas of economic engineering, not only by the amount of research developed in that area, as well as the constant investment needs and good results of those investments which the modern world requires (Kim et al., 1986).

Some researchers believe that if companies use sophisticated methods, are better equipped for better performance. Thus, several studies have been made to understand if companies use those methods. Since the 1950s that the academic community tries to convince companies that using these methods would achieve better results (Farragher et al., 2001). It was already from the year of 1960, that studies show that these sophisticated methods begin to have a better acceptance by companies (Istvan, 1961). Thus, from 1970 these methods become more common in companies (Klammer, 1972, Klammer, 1973a, Brigham, 1975).

Since the year of 1980, some studies have shown that despite an increase in the use of sophisticated methods, the non-sophisticated methods are still widely used (Gordon et al., 1988). Beyond that, some authors argue that the use of sophisticated criteria does not invalidate the use of other criteria, as they suggest that, although companies use sophisticated criteria, does not mean that their decisions rely on them (Rosenblatt and Junker, 1979, Pike, 1984).

Over the following years, several studies were developed in order to know the degree of sophistication of companies in which researchers concluded that small firms are relatively less sophisticated than large companies (Mustapha and Mooi, 2001, Graham and Harvey, 2002, Farragher et al., 2001, Pike, 1984). These facts have remained to the present day as more recent studies show that sophisticated methods are increasingly a part of the most common practices used by companies around the world (Verbeeten, 2006, Sandahl and Sjögren, 2003, Hermes et al., 2007, Bennouna et al., 2010, Alkaraan and Northcott, 2006, Carr et al., 2010).

The NPV and IRR are the most common methods (Ryan and Ryan, 2002) and those which theoretically provide better results. However, the more theoretical managers prefer the NPV and the most practical prefer the IRR (Pike, 1996). This can be explained by the fact that the IRR is more easily interpreted (Kim et al., 1986). However, non-sophisticated methods, including the Payback Period, are quite widespread by the companies and are often used by mature CEOs, who are in functions for many years in the same company and without having an MBA (Graham and Harvey, 2001).

Regarding the national scene, few studies have been conducted. However, it appears that, in some studies, companies prefer the Payback Period (Gouveia, 1997, Rodrigues and Armada, 2000), while in other studies is preferred the NPV (Rego, 1999). In Portugal, as in other countries, it appears that the majority of the companies prefer to combine more than one method (Rodrigues, 1999).

2.3. The association between the use of sophisticated project evaluation methods and companies performance

During the 1970s, Klammer (1973b) assumed that if a company uses sophisticated methods, then that same company will have to be better results than others who do not use them. To prove that hypothesis, Klammer (1973) conducted a study based on a survey sent to 369 firms present in a database called *Compustat*.

However, after analysing the replies to the survey, Klammer (1973) concluded that there is no evidence that relate to companies performance by the use of sophisticated methods, adding that the mere adoption of these methods is not enough for better performance and for that, other factors such as Product Development, Marketing and others, may have a greater impact on performance. Based on this study, many authors tried to prove that this relation exists (Kim, 1982, Pike, 1984, Haka et al., 1985, Farragher et al., 2001). In the study of Farragher et al. (2001), they used indicators that were adjusted to the type of industry of each company. They developed a model that would allow to examine the relationship between the performance of a company with its degree of sophistication. In that model, the variables were based on characteristics of the company under study, for example, company size, its degree of sophistication, its operating risk, the average assets per employee in comparison to the average of companies in that sector, among others. However, the results were consistent with those of the previous studies, which is, there is not a clear relation. Furthermore, Farragher et al. (2001) concluded that their study does not support the hypothesis that better performing companies apply more sophisticated methods than firms with poor performance. It should be noted that these studies refer to companies in the United States and United Kingdom.

Thus, researchers have dedicated themselves to understand whether these findings also verified in other countries. A study conducted in Malaysia, failed to prove that the fact that companies have a high degree of sophistication had no relation to his performance (Mustapha and Mooi, 2001).

Sandahl and Sjögren (2003) performed a study that allowed to realize which methods are used by Swedish companies. Thus, concluded that the most popular method, for more unexpected it may seem, is the Payback Period, in contrast to what is taught in the academic environment. On the other hand, this evidence, settles the fact that traditionally, this method is very rooted, beyond its simplicity of application. However, sophisticated methods are also used by many companies, particularly the ones of the public sector. As all the authors cited herein, they also believe that the use of sophisticated methods will lead to better results in the future, however they did not find evidence of this relation (Sandahl and Sjögren, 2003).

A study comparing the behavior of companies in the Netherlands and China concluded that the economic development level of the country where the company is located influences its use of capital budgeting techniques. But, this study failed to secure the relation between the sophistication of methods used and the companies' performance (Hermes et al., 2007).

A very recent study conducted for Canadian companies also failed to show this relation even though many companies have a good degree of sophistication (Bennouna et al., 2010).

In Portugal, to the author's best knowledge, no study has been done, as it had as objectives verify whether this relation exists.

From all these studies, the authors pointed out some issues. The fact that all these studies were performed based on surveys is considered a problem, because the survey response rate is always very low, so the scope of the studies may be compromised. The definition of variables to be studied may not have been the most correct, so there is no association between the use of sophisticated methods and the companies' performance. The statistical model may not be the appropriate model to best describe this relation. Another problem is due to the fact that large companies with good performance do not allow to understand if that performance is related to the use of those sophisticated methods, since they already have good economic performance. This gives rise to what in economics is known as the *post hoc* fallacy.

Another possible explanation for the weak results on the association between sophistication of methods and companies' performance, relates to the fact that even the sophisticated methods (e.g. NPV and IRR), can not give the most precise or accurate results. In fact, traditional evaluation methods are inadequate to deal with some investment characteristics, like risk and uncertainty. If firms would use other methods to analyze their investments and if those methods provide more accurate results the relation between the use of more precise project evaluation methods and the companies' performance could be verified. A way to deal with those issues is by using the Real Options Theory.

2.4. Real Option Theory evaluation

Traditionally, the NPV and the discounted cash-flow methods (DCF) have been used to evaluate investment projects (Graham and Harvey, 2002, Ryan and Ryan, 2002). However, given that today investments are characterized by high risks and uncertainty, DCF methodologies are inadequate to deal with these issues. These traditional techniques make implicit assumptions, like the reversibility of investments. In other words, an investment can be undone and the expenditures recovered. On the other hand, if a firm do not undertake the investment now, it will not be able to do it in the future and this will become unrecoverable (Dixit and Pindyck, 1994).

Although, there are some investment projects that have these features, most of them do not have it. In fact, the ability to delay an investment, in order to obtain more information and thus reducing uncertainty, provides management with a valuable opportunity to modify both investment and the strategy to follow, in order to get better future opportunities or to reduce future losses.

Thereby, this possibility can be seen as an option due to the fact that a company has the opportunity to invest, or simply not investing, similar to a financial call option (Dixit and Pindyck, 1994).

From this premise, capital budgeting can be treated in the context of what Myers (1977) called Real Options approach. Additionally, Trigeorgis (2000) stated that "an options approach to capital budgeting has the potential to conceptualize, and even quantify, the value of options from active management. This value is manifest as a collection of corporate real options embedded in capital investments opportunities…"

Unlike traditional methods, the Real Options Theory centres on the valuation of the managerial flexibility to answer to different scenarios with high levels of uncertainty. This theory is known as a modern approach for economic valuation of projects under uncertainty (Marreco and Carpio, 2006).

The concept of real options arises from financial options. Its foundations lay in the Nobel Prize awarded work on the pricing of financial option contracts, developed by Fisher Black, Robert Merton and Myron Scholes. The option-pricing theory had applications for all kind of investments, whether they are real or nonfinancial (Black and Scholes, 1973). Thus, the real options theory is a natural extension of the option-pricing theory.

2.4.1. The financial options

To a better understanding of the real options theory, it is important to introduce the concept of financial call options and afterwards the definition of real options.

According to Black and Scholes (1973), "An option is a security giving the right to buy or sell an asset, subject to certain conditions, within a specified period of time". Options represent rights, therefore the yield of an option can never be less than zero, independently of the underlying asset.

There are two types of basic options, the ones that give the right to buy (call) an asset at a pre-specified price (exercise price) in specified period (time to maturity) and those that give the right to sell (put) an asset in exchange for receiving an exercise price in a pre-specified time (time to maturity).When the option exercise price is below the current price of the underlying asset (for a call option), or above the current price of the underlying asset (for a put option), it is said that the option is "in the money". Otherwise, it is "out of the money".

Options can be either European or American. When the option can be exercised only on a specified future date that option is designated of "European option". On the other hand, when the option can be exercised at any time up to the date the option expires that option is designated of "American Option".

It was demonstrated that the value of an European call option (C) can be estimated using the Black-Scholes model (1973), and it only depends on two variables - price of the underlying asset (V) and the current date (t) - and five parameters: the option exercise price (K), volatility of the asset (v), the risk-free rate (r), the expiration date of the option (T) and the distribution rate of dividends (δ). The task now is to understand how we can assess real assets by the method of real options based on the knowledge developed about financial options.

It is assumed, for now, the analogy that while in the financial options, the underlying assets are financial assets - stocks, for example – in real options they are real assets - projects, machinery, etc. - whose price would be arbitrated by the present value of operating cash flows.

It is known that a financial asset can not have negative value, in the case of real options it can happen for a particular project taking negative NPV.

In the case of financial options, in most cases, the exercise price is determined, while in real options where the exercise price will be the investment required for the completion of the project, it is commonly assumed to be stochastic. It is noteworthy that in the exercise of real options there is the construction time, in other words, can not get the asset immediately.

In particular financial option, the model's volatility (v) refers to the standard deviation of the returns of the underlying asset prices, while in real options is the volatility of cash flows of the project.

The parameter δ in the financial options regards to the distribution of dividends of the base asset, whereas in real option refers to the cash flows generated by the project.

2.4.2. The Black and Scholes option pricing model

Based on assumptions such as that stock prices follow a Geometric Brownian Motion (GBM), and also it would be possible to create risk-free portfolio consisting of stocks and European options written on such purchase, Black & Scholes (1973) presented a model for pricing financial options, which became a reference for developing the modern theory of modeling and pricing of financial assets. This work bequeathed to finance the use of stochastic calculus, an appropriate tool for the treatment of functions and stochastic variables in continuous time.

Next, it will be presented the Black and Scholes closed formula for pricing European call options and in the Annexes, can be found the development of the model to the partial differential equation of Black and Scholes:

$$C(V,t) = VN(d_1) - Ke^{-r(T-t)}N(d_2) \tag{7}$$

Subject to,

$$d_1 = \frac{\ln\left(\frac{V}{K}\right) + \left(r + \frac{v^2}{2}\right)(T-t)}{v\sqrt{(T-t)}} \tag{8}$$

$$d_2 = d_1 - v\sqrt{(T-t)} \tag{9}$$

Where,

- $N(.)$ is the cumulative distribution function
- $T - t$ is the time to maturity
- V is the spot price
- K is the strike price
- r is the risk free rate
- v is the volatility of the returns of the underlying asset

Later, Merton (1973) extended the formula for the case of assets that pay dividends:

$$C(V,t) = Ve^{-\delta(T-t)}\mathrm{N}(d_1) - \mathrm{K}e^{-r(T-t)}\mathrm{N}(d_2) \quad (10)$$

Where δ is the dividend yield, which is percentage of profits distributed as dividends to shareholders regularly.

2.4.3. The Real Options Definition

There are some definitions of real options, however all of them tend to refer to the same concepts. Thus, two definitions are presented as follows.

Copeland and Antikarov (2003) defined real option "as the right, but not the obligation, to take an action (e.g., to defer, to expand, to contract or to abandon) at a predetermined cost, called exercise price, for a predetermined period of time – the life of the option".

Another definition was given by Kogut and Kulatilaka (2001), where Real Options were defined as "an investment decision that is characterized by uncertainty, the provision of future managerial discretion to exercise at the appropriate time, and irreversibility".

Therefore, an opportunity to invest is similar to a financial call option. If it is possible to find a call option like an investment opportunity, the value of that option would tell investors something about the value of the investment opportunity. So, it has to be established a relation between the investment project characteristics and the variables that are needed to value a call option, and this is shown in Table 1.

Table 1 - Analogy of the call option and the project characteristics

Project characteristics	Variable	Call option
Present value of expected cash flows	S	Stock price
Present value of investment outlays	X	Exercise price
Length of deferral time	t	Time to maturity
Time value of money	r_f	Risk-free rate
Volatility of project's returns	σ	Variance of stock returns

2.4.4. Common types of real options

In this subsection a summary of the most common real options will be presented. Although there are several types of real options, Trigeorgis (2000) argues that the most common are the defer, time-to-build, alter operating scale, abandon, switch and growth options.

The defer option gives the holder the ability to wait to invest the money. This means that, one with an investment opportunity has the option to spend the money now, or wait for more information about the investment or simply wait for the resolution of the uncertainty (Dixit and Pindyck, 1994). These options are frequently applied on investments in industries of natural resource extraction, real-estate development, farming and many other projects that can be deferred (Trigeorgis, 2000).

Many investment projects have some particular characteristics, such as requiring a construction and or start-up time that does not allow to return any profit until it is completed or involving some decisions and cash expenses that may occur sequentially over time. Real options are particularly suitable to the evaluation of these projects. Therefore this option gives the holder the possibility to abandon the project, if certain events, specially unfavourable, occur or damaging information arrives (Majd and Robert, 1987). R&D intensive industries, like pharmaceuticals, long-development capital-intensive projects and start-ups are examples of investments for which these types of options may be applied.

The option to change the operating scale (to expand, to contract, to shut down and to restart) provides the decision maker the potential, for example, to expand the scale of production or to accelerate resource utilization, if market conditions are promising. Otherwise, if the market conditions are unpromising, the operating scale can be reduced (Trigeorgis, 2000). These options are important in all kind of production industries, natural-resource industries, facilities planning and construction, consumer goods and commercial real-estate firms.

In some situations, markets changes reveal to be adverse to the investment. It becomes then necessary to abandon it and, perhaps, realize the resale of capital equipment and other assets. This can be extremely important in order not to lose an entire investment and the option reasoning offers a away to evaluate this possibility (Myers and Majd, 1990). Abandon options are important in capital-intensive industries, such as airlines and railroads, financial services and introduction of new products in uncertain markets.

The option to switch allows the decision maker to evaluate the possibility to switch the inputs or the outputs of their business. This possibility will ensure a great adaptive flexibility to market changes. For example, if there are changes in prices or demand, the management can change the types of products produced (outputs), giving product flexibility. On the other hand, the same types of products can be produced from different types of raw material (inputs), giving process flexibility (Kulatilaka and Trigeorgis, 1994, Trigeorgis, 2000).

In some investment projects, the possibility to expand in the future may exist. The growth options can be interpreted like the acquisition of a capability that allows the firm to take better advantage of future growth opportunities, unlike companies that do not acquire these options (Kulatilaka and Perotti, 1998). These options are important in all infrastructure based or strategic industries such as high tech and R&D, industries with multiple product generation or application like pharmaceutical, multinational and strategic acquisitions.

2.5. Concluding remarks

In this chapter, a critical literature review of traditional project evaluation and the ROT was made. To do that, a brief description of the traditional project evaluation methods was presented, and the application of these methods by companies was analyzed. Also, the relation between the use of this methods and companies performance were studied. The ROT was introduced, starting by explaining its theoretical foundations, definition and ways of calculation. The Black and Scholes option pricing model was also presented. In the next chapter an overview of the application of ROT to the energy sector is presented.

3. Application of the real options theory to the energy sector

The energy sector, since 1970, has suffered market, regulatory and technological changes. In this new context, traditional capital budgeting methods are no longer sufficient to properly evaluate investments in this sector. In fact, this sector has moved from a regulated and monopolistic sector to a deregulated, uncertain and highly competitive sector (Awerbuch et al., 1996).

This change opened the way to the application of the real options theory. To illustrate the increased importance of the real options approach on the energy sector, in the following paragraphs, an "historical" perspective is attempted and several examples are briefly described. The application of the real options theory to the renewable energy investment projects will be described in more detail in the next subsection. The first applications of this theory go back to 1979, with the work of Tourinho (1979). Brennan and Schawrtz (1985) applied option pricing methods to the evaluation of irreversible natural resources using the Chilean copper mines. At the same time, other authors developed work in the energy sector, more specifically in the oil industry, like Siegel et al. (1987), Paddock et al. (1988) and Ekern (1988).

In the years 1990 to 2000, Dixit and Pindyck (1994), Trigeorgis (1996) and Amram and Kulatilaka (1999), contributed to the development of the real options approach application/use publishing books on this issue, giving an emphasis to examples and case applications, in several industries and or markets, including the energy sector.

In 1996, Felder (1996) argued that an increase in the use of financial theory and methods would be expected, as electricity industry becomes more deregulated.

Ghosh and Ramesh (1997) investigated the development of an options market for bulk power trading in a market setup while considering power systems planning and operational constraints and/or requirements. They proposed a solution to option pricing in electricity futures prices. They also noted that a massive change in the electric power supply industry was about to occur.

One year later, Hsu (1998) wrote an article arguing that the owners of natural gas power plants should view their assets as a series of spark spread call options. The author also stated that ignoring this concept will inevitably lead to financial losses.

Frayer and Uludere (2001) demonstrated how a real-options based valuation reveals and correctly quantifies the value of efficient plant operation in face of volatile electricity market prices. The authors used a pricing model that is a derivation of the spark-spread principle and adjusted the Black-Scholes formula for pricing options on real assets. The analysis showed that for the used example a peaking gas-fired facility may be more valuable than a coal-fired plant, contradicting the results achieved with the traditional DCF methods. Also, Deng et al. (2001) presented a methodology to valuing electricity derivatives. They also developed a real options valuation for generation and transmission assets.

Armstrong et al. (2004) presented a case study on oilfield production enhancement. The aim of their study was to evaluate the option to acquire more information. To do that, they incorporated in a real options model a Bayesian analysis. Through their example, they showed that Bayesian analysis coupled with real options provides a general framework for evaluating the option to obtain additional information. Moreira et al. (2004), studied thermal power generation investments for the case of Brazil. The authors resourced to a stochastic dynamic programming approach and to real options theory to develop a model to calculate the investment attractiveness for power generators to assess the regulatory effect on the investment attractiveness, to evaluate the effect of the thermo generation share upon the system expansion cost and to assess the effect of thermo power operation flexibility on the system operating cost.

Hlouskova et al. (2005) presented a model for the unit commitment problem base on real option theory. The authors implemented the real options model of Tseng and Barz (2002) and applied it to value and optimally operate an electricity generation turbine in German market. At the same time, Madlener et al. (2005) applied a dynamic technology adoption model for the evaluation of irreversible investment options for electricity generation technologies. They took into account the uncertainty, the life-cycle capital and the operation costs. Their work contributed to the work of Moreira et al. (2004), as the authors used a model accommodating plant availability, load duration curves, and irreversibility of investment similar to those of Moreira et al. (2004).

One year later, Laurikka and Koljonen (2006) studied the impacts of the European Union Emission allowance Trading Scheme (EU ETS) on investment decisions in Finland. They extended the traditional discounted cash flow analysis to take into account the value of two real options. Their study showed that the uncertainty regarding the allocation of emission allowances is critical in a quantitative investment appraisal of fossil fuel-fired power plants. Blyth and Yang (2006) also focused in this issue and developed a work for the International Energy Agency (IEA), to quantify the impacts of climate change policy on power investments. They used real options theory and modelled prices uncertainty with stochastic variables. In the same year, van Benthem et al. (2006) developed a model, using options theory, to calculate the value and timing strategy of investment in a hydrogen infrastructure as a transport fuel. Chorn and Shokhor (2006) presented a work that extends the applicability of real options theory from a valuation technique to a policy guidance tool. That was the first demonstration of a mathematical union between two techniques of decision, real options and the Belman equation, providing a generalized policy framework that gives risk management of investments. Nevertheless to date there was no quantitative demonstration of the proposed framework. Deng and Xia (2006) proposed a real options model to value a tolling contract. They used dynamic programming and valuated function approximation by Monte Carlo simulation. Also in 2006, Marreco and Carpio (2006) presented a valuation study of operational flexibility in the complex Brazilian Power System. They applied the real options theory in order to create a methodology that could compute the fair values to be paid to a thermal power generator merely for its availability to the system.

In 2007, Botterud and Korpas (2007) studied the effect of power system restructuring on investments in new generation capacity and developed an optimization model for optimal timing. They used real options theory to deal with the question of how uncertainties in future demand influence prices in the electricity market. Their model can be used to analyse the interrelated dynamics of electricity spot and capacity price, and its effect on profitability and optimal investment timing.

One year later, Prelipcean and Boscoianu (2008) presented an integrated framework to evaluate decisions in energy investments. Their framework incorporated Real Options Theory and Artificial Neural Networks.

In 2009, Abadie (2009) conducted a study which aimed to contribute to the development of valuation models for long-term investments in energy assets, using real options theory. Bonis et al. (2009), studied a real investment case related to the expansion of Endesa in Latin American, applying real options theory. Fuss et al. (2009) presented a real options model to evaluate the impact of climate change policy to the energy sector. Uçal and Kahraman (2009) proposed a new fuzzy real options valuation model to evaluate oil investments.

In 2010, several works applying real options to the energy sector were presented. Fan and Zhu (2010) developed a real options model to help in the decision-making process on overseas oil investment decisions. Fleten and Näsäkkälä (2010) presented a case study of gas-fired plants using real options analysis, in Scandinavia. They also provided upper and lower bounds for investment thresholds and plant values that depend on the degree of operating flexibility of the plant.

This description does not intend to be exhaustive but rather demonstrate the diversity of methods and problems approached under the Real Options Theory. Annex A.2 Historical perspective of the reviewed studies applying Real Options Theory to the energy sector summarizes the historical perspective of the studies reviewed in this section, applying Real Options Theory to support decision making on the energy industry, companies and markets.

3.1. Application of the real options theory to renewable energy sources (RES) investment projects

In this section the presentation of the applications of the real options theory to renewable energy will be addressed, focusing on three major areas: power generation, policy evaluation and R&D investments/programs.

3.1.1. Real options theory in Power Generation investment

To the authors' best knowledge, one of the first applications of the real options theory to the renewable energy field, wind energy exploitation more precisely, dates back to 2002, by Venetsanos et al. (2002). The authors identified a framework to evaluate renewable energy power projects. Firstly, they considered the uncertainties and the directly related resource attributes, which are inherent to the energy production. Secondly, they identified the real options embedded to a wind energy project. Thirdly, they evaluated the project, according the real options theory. For that they used the Black-Scholes Model. Finally, they compared the results of their model with the traditional Discounted Cash Flow technique. The major findings of their work were that the option value was positive, while the net present value was negative.

It was only on 2007, in Norway, that Kjarland (2007) applied real options theory to assess the value of hydropower investment opportunities, and to find the relation between price level of electricity and optimal timing of investment decisions in hydropower sector. They used the framework developed by Dixit and Pindyck (1994).

Following the same line of research, Bockman et al. (2008) presented a real options based method for assessing small hydropower projects. They applied their method to three different Norwegian hydropower projects.

In 2009, Muñoz et al. (2009) developed a model to evaluate wind energy investments. The authors used a stochastic model for the parameters affecting the NPV and a real options model to evaluate the probabilities to invest, wait or abandon the project. They also applied their model to several case studies.

Martínez-Ceseña and Mutale (2011) showed that projects planned with Real Options methodology show higher expected profits than projects using other methods. They also developed an advanced Real Options methodology for renewable energy generation projects, illustrating their methodology in a hydropower case study.

3.1.2. Real options theory in policy evaluation

One of the first applications of the real options theory to this area dates back to 2006, by Yu et al. (2006). They used real options techniques to evaluate switching tariff for different wind generation assets, and to identify optimal switching policies and values, in Spanish electricity markets.

Two years later, in 2008, Kumbaroğlu et al. (2008) presented a policy planning model that integrates learning curve information on renewable power generation technologies into a dynamic programming formulation containing real options theory. Note that the model was successfully applied in Turkey.

One year later, Siddiqui and Fleten (2010) examined how a staged commercialization programme for an unconventional energy technology could proceed under uncertainty. Lee and Shih (2010) presented a policy benefit evaluation model using real option pricing techniques and considered uncertainty and others factors that impact policy for developing renewable energy. Their framework allows to assess volatility, uncertainty, and managerial flexibility in policy planning.

3.1.3. Real options theory in R&D investments/programs

One of the first applications of the real options theory to this area dates back to 2003, by Davis and Owens (2003). They quantified the value of the United States federal non-hydro renewable electric R&D program based on a real options model. They also use that model to determine the optimal level of annual federal renewable energy R&D expenditures.

In 2007, Siddiqui et al. (2007) assessed the strategy for renewable energy R&D in the United States. They studied the deterministic approach employed by the Department of Energy and the real options model developed by Davis and Owens (2003). For that purpose, they developed a real options model, but on the contrary of Davis and Owens' model, they used a binomial lattice structure. They argued that a binomial lattice reveals the economic intuition underlying the decision-making process, while a numerical example illustrates the option components embedded in a simplified representation of current US Federal renewable energy research, development, demonstration and deployment. Their model has been implemented in MATLAB®. Annex A.3 Historical perspective of the reviewed studies applying Real Options Theory to the summarizes all the studies that applied Real Options Theory to RES that are referred in this section.

3.2. Concluding remarks.

In this chapter, a literature review about the application of the ROT to the energy sector in general and in particular to the RES was presented.

An increase on the interest and application of real options theory to the energy sector decision making has been noticed during the last years. As seen in the literature review presented, this theory has been applied in several fields of the energy sector, from generation to evaluation of policies. This increase reveals that the interested parties in the energy sector now understand the limitations of the traditional techniques, given the potential of the real options theory. The RES sector is no exception and a few studies using the Real Options Theory appeared recently in the literature, although this particular literature is still limited.

RES projects have particular characteristics that imply selecting methods capable to assess their correct value taking into account these particularities. Namely, these projects have high initial costs, high financial risk and uncertainties. These uncertainties are caused by their natural sources variability, the possible changes in the support schemes and by their learning curves exhibiting very steep slopes. The interest of these projects is also indirectly affected by the prices of the fossil fuel price and consequently by the prices of the electricity and, as so, the markets uncertainty also affects these kinds of projects. Taking into account the exposed reasons, Real Options Theory seems to be an evaluation method that can provide a more realistic value of a RES investment project. However, there seems to exist a lack of application of this technique to this field and, as so, the authors frequently resource to the simulation of the application. Therefore, to overcome this lack of application, the ROT will be applied to a Portuguese photovoltaic investment.

4. Project evaluation of a photovoltaic investment

The Sun is our main source of energy, responsible for maintaining the various forms of life on Earth. This is practically an inexhaustible resource when compared with the scale of our existence on this planet.

The Sun annually provides to the atmosphere, a huge amount of energy (valuated in $1,5\ x\ 10^{18}\ kWh$) corresponding to about 10,000 times the world energy consumption observed during the same period. However, this source is considered too dispersed, with the resulting advantages and disadvantages. Among the disadvantages, it should be noted without doubt the need for major catchments surfaces for its use (for example, the Moura's photovoltaic power station for an installed capacity of $62\ MWp$, occupies an area of approximately 114 hectares). Its great advantage is that it is an energy source fairly distributed (DGEG, 2010).

In Portugal, the available potential is quite considerable, being one of the European countries with better conditions for exploitation of this resource, featuring an average annual number of hours of sun, which varies between 2200 and 3000 on the mainland, and between 1700 and 2200, respectively, in the Azores and Madeira (Figure 2). In Germany, for example, this indicator varies between 1200 and 1700 hours (Figure 1) (DGEG, 2010). Also, the use of solar thermal and photovoltaic is still far short of the potential of this resource, available in the country. It is estimated that in 2003 the installed capacity of solar PV systems was about 2 MW, of which only 20% refer to facilities connected to the public grid.

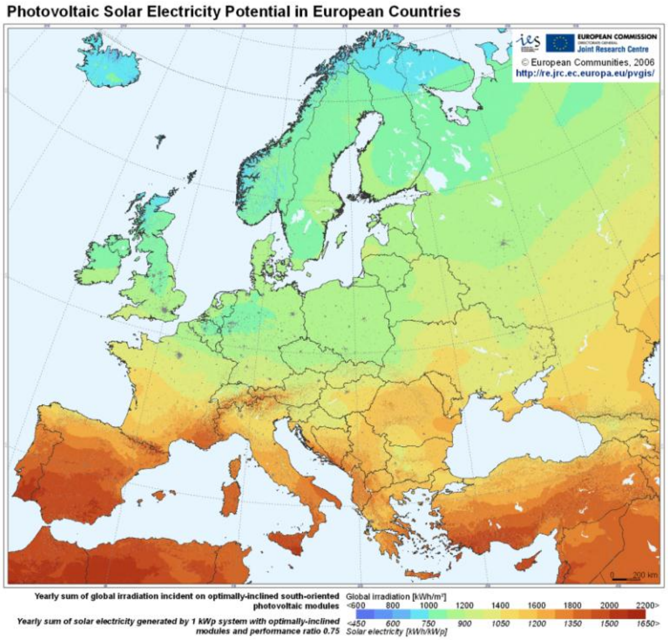

Figure 1 – Photovoltaic solar electricity potential in Europe (Šúri et al., 2007)

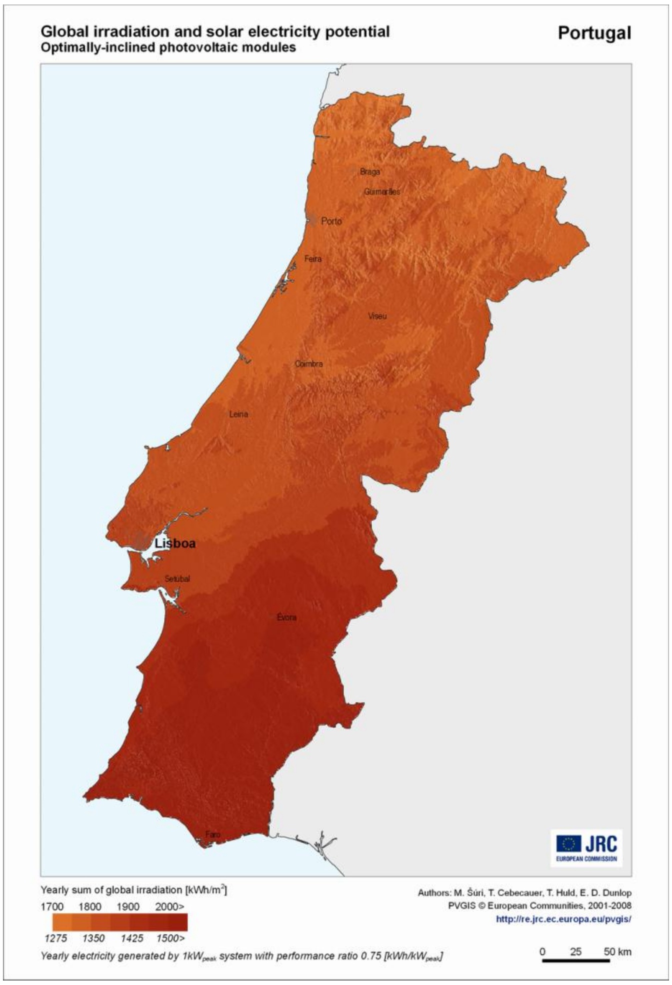

Figure 2 – Global irradiation and solar electricity potential in Portugal (Šúri et al., 2007)

In an effort to promote economic development, reduce dependency on external sources and combat the forces of climate change, the Portuguese Government expanded the objectives to be reached in the Resolution of the Council of Ministers nº 63/2003, dated 19 October, for various sources of renewable energy. The rate of electricity produced from renewable energy sources by 2010 has been set higher, going from its initial figure of 39% to 45%. These objectives will be met by increasing all areas of energy supply, by the promotion of energy efficiency and the wise use of energy, orienting the growth of energy consumption at a level lower than the growth of the country’s wealth measured in monetary units by the GDP – Gross Domestic Product.

The opening of international competitive bids in Portugal brought about a boost of potential for renewable energy, such that industrial clusters were created, which drastically changed the previous paradigm where the creation of wealth for renewables was stunted. Here, wind energy made notable contributions, with its goals for production increasing from 3,750 MW to 5,300 MW, alongside the obligation placed upon the winners of state contracts who will create 2,000 direct and 10,000 indirect jobs in the sector, thus increasing national production from 15% to 80% (MEID). Solar energy has enormous potential for development in Portugal over the next decade. Its complementarity with other renewable technologies, by being generated at times of peak consumption, leads to setting a target of 1,500 MW of installed power in 2020 through the implementation of many programs, and the development of this capacity must follow the technological efficiencies progress and reduce costs associated with these technologies, including solar photovoltaic and thermoelectric concentration (MEID).

This reality opens a window of opportunity for investors. So, it is important to have good project evaluation methods to evaluate correctly this kind of investments. However, before moving to the evaluation itself, it is important to know the particularities of an investment in photovoltaic.

Szabó et al. (2010) presented in their work a SWOT analysis of photovoltaic investments in comparison to gas based power technology (Table 2). Their findings where very interesting, especially for situations where the market of photovoltaic is regulated, which is the case of Portugal. Similarly to many EU countries, Portugal has risk mitigation support schemes (such as feed-in-tariff) which reduced most of the risks in investing in this sector.

Table 2 - SWOT analysis of photovoltaic investments in comparison to gas based power technology

Strengths
Modular investment (can be divided into phases)
Zero fuels cost/no fuel price risk
Low maintenance cost
Near zero CO_2 emission
Small operational capacities compared to the combustion based technologies
Overall, space is not a limiting factor for PV implementation
Dispersed supply points – can be beneficial to certain networks
Output often correlates with the peak operation hours caused by air conditioning
The most adequate sites are usually close to the consumer
The operation does in general not require staff, only maintenance
Weaknesses
High up-front cost compared to the fossil fuel technology
Variable output
Restricted utilization hours: the fixed cost is distributed on a smaller base
Opportunities
Possible contribution to system adequacy (grid supporting services like frequency and voltage control)
New system operation techniques
Net metering
The correlation of operation hours is low with wind: therefore their combined use may decrease the output variability (further research is needed)
Improvement in storage technologies (batteries, etc.)
Employment rates for solar PV are 7.26–3.15 jobs/MW new installed with gradual annual

reduction (Heavner and Del Chiaro, 2003)
Threats
Additional grid connection requirements
Grid infrastructure
Additional system reserve requirements

4.1. Photovoltaic investment data

The investment studied in this work was based on the Portuguese Serpa Solar plant. This solar plant is located in Serpa, Alentejo, which is one of the locations with more solar irradiation potential, as it can be seen in Figure 2.

This solar plant is already in operation since 2007. However, one of the objectives of this work is to show that if other project evaluation techniques (like ROT) might have been used, the decisions about construction or not could be different. Also, aims to prove how traditional evaluation techniques may fail in the evaluation of RES projects.

The source for most of the following data was Maso (2007). However, that document did not contain any information related to Operations and Maintenance (O&M) cost and the discount rate. In order to get that information the work of Bensebaa (2011) was used, where the author justifies that the annual O&M cost should be 0,4% of the investment and the discount rate 7% for this type of projects.

Table 3 - Technical and financial parameters of the project

Technical and financial parameters of the project	Values
Number of PV panels	52000
Nominal Power	11 MWp
Power efficiency	11-14 %
Direct Capital Cost	3,83 €/W
Indirect Capital	1€/W
Investment	53130000 €
Electricity production (annual)	18 GWh
Feed-in tariff	0,32 €/kWh
O&M Cost (% of the investment)	0,4 %
Project life time	25 years
Discount rate	7 %

4.2. The traditional evaluation

To evaluate under the traditional approach, the NPV method was used. As mentioned earlier, this method is favored by nearly all the manuals for project evaluation, mainly for being the most consistent, from a theoretical point of view, in the context of project selection.

The analysis made was developed in the simplest way and does not take into account all the financial data of the project, namely depreciation and taxes. However, it can be seen as the best possible case, therefore the true result can only be at most equal to this analysis.

Taking into account the financial data in the Table 3, the following financial data for the calculation of the cash flows of the project were obtained (Table 4). The following table summarizes all the financial forecast for this investment. That financial data can be seen in Annexes A.4 and A.5.

Table 4 – Summary of the annex A.4 and A.5

Operating Projections	Years			
	0	1	...	25
1. Revenues		5760000,00 €	...	5760000,00 €
2. O&M		212520,00 €	...	212520,00 €
Operating profit (1-2)		5547480,00 €		5547480,00 €
Investment	53.130.000,00 €			
Discount factor (7%)	1,00	0,93	...	0,18
PV	53.130.000,00 €	5.184.560,75 €	...	1.022.118,63 €
NPV	11.518.019,61 €			

As it can be seen in this analysis, this project as a NPV of 11,52 M€, which is relatively small compared to the amount of investment that have to be made (53 M€). Moreover, it is necessary to take into account that this is the best-case analysis. Thus, the situation does not seem the most favorable to the investment. Yet, considering the decision rule in 2.1.2.1 Net Present Value, the project should be accepted.

4.3. Uncertainties

Like the projects of today, this project has uncertainties that are not taken into account in that evaluation.

Kaslow and Pindyck (1994) identified the most important uncertainties related to energy production - utilisation and the attributes, which interact with them, as can be seen in table 5.

Table 5 - Uncertainties related to the energy production

Uncertainty	Relevant resource attributes
1. Fossil fuels price	Operating costs
2. Environmental regulations	External costs
3. Demand	Location flexibility Modularity and Lead-time Capability Availability
4. Supply	Location flexibility Modularity and Lead-time Capability Availability
5. Initial Capital Cost and technological issues	Initial capital requirements Modularity and Lead-time Location flexibility
6. Market structure	Overall costs

Electricity production using fossil fuel based technologies incurs high variable costs and is vulnerable to oil price shocks. The result is extended operating costs volatility, which is directly reflected on electricity prices. RES with high fixed but low variable costs can provide price stability and a good hedge against the risk of fuel price volatility (Venetsanos et al., 2002).

However, this type of uncertainty does not arise in this project, because of the fact that the Portuguese photovoltaic market is regulated, this means that fossil fuels price volatility does not affect the performance of photovoltaic.

Environmental regulations uncertainty is closely related to the fossil fuel price uncertainty which, as mentioned earlier, does not arise in this project.

Demand uncertainty can be seen from two general perspectives (Venetsanos et al., 2002):

- Short-term perspective ranging from a few hours to a few days: The demand is quite predictable, and electricity generators, must consider the arrangements they should make (for example, power purchase) to meet expected demand levels.
- Long-term perspective: Electricity producers must make predictions about future energy requirements, the additional resources that may be required to meet the future peak system capacity and the long-term power purchase agreements (PPAs) they should make.

This type of uncertainty does not affect this project, because of the fact that all the produced energy is sold. This happens because, as said before, the market is regulated.

Supply uncertainty is related to demand uncertainty. The supply systems (generation and transmission/distribution) ensure that the equipment operates properly and efficiently, which means that in case of a forced outage, uninterrupted electricity supply will be maintained for as long as possible, (Venetsanos et al., 2002)

The initial Capital Cost uncertainty refers to the initial investment cost, as well as the additions to the installed capacity. The technological uncertainty relates to the risk that the installed resources can become economically obsolete, due to technological changes, before Capital Costs are fully recovered or the investment provides positive cumulative CF. Technology is an important driver of energy development, and technology costs change over time. In fact, one of the most important factors shaping the results of energy models are the assumptions they make about technology learning (Energy Innovations, 1997, IEA & OECD, 2006)

The unit costs of technologies, typically measured in $/installed kW, change over time. A measure of this learning is the “progress ratio”, which is the reduced cost per unit installed for each doubling of global cumulative capacity, given as a percentage of the initial cost. The “learning ratio” refers to the percentage reduction in cost over the same doubling period (i.e., it is 100% minus the “progress ratio”) (Winkler et al., 2009). Learning curves show the decline in costs (either in S/kW, i.e. units of installed capacity, or sometimes in levelized costs reported in units of c/kWh for electricity generation technologies) as cumulative electricity production doubles. Figure 3 shows which RET costs decline fastest.

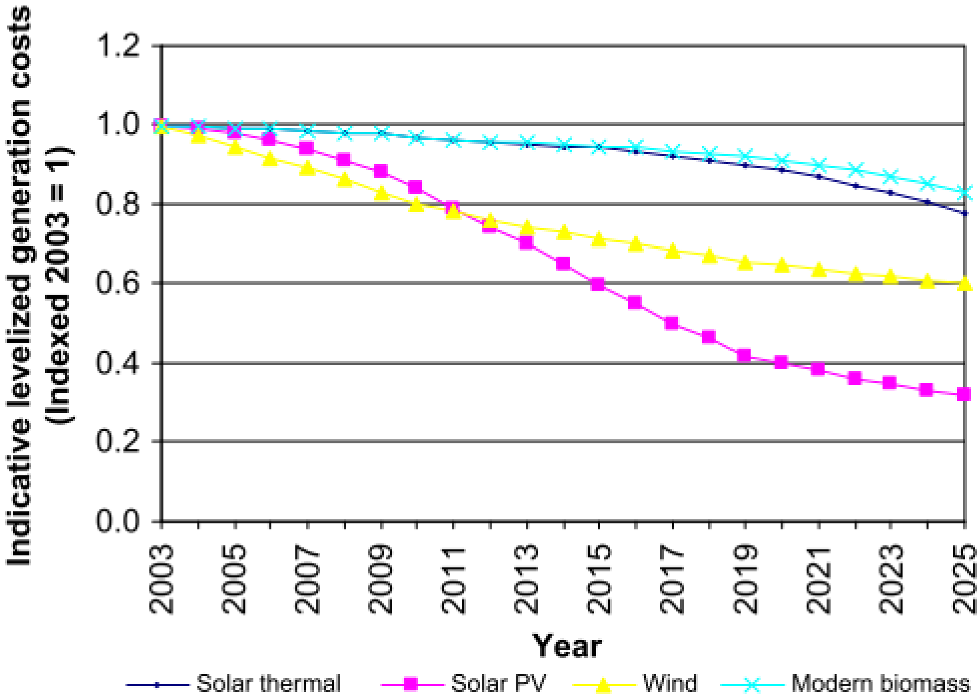

Figure 3 – Reduction in costs, with levelized costs (c/kWh) indexed for base year 2003 (UNEP, 2006).

Winkler et al. (2009), presented in their work some learning ratios for photovoltaic. They showed that the range of learning ratios in the literature is for 17-68%. However in their study they estimate a learning ratio of 25% for 2003 to 2025.

Nemet (2006) summarized the learning curve model in three equations:

$$C_t = C_0 \left(\frac{q_t}{q_0}\right)^{-b} \quad (11)$$

$$PR = 2^{-b} \quad (12)$$

$$LR = (1 - PR) \quad (13)$$

Where C_t (in \$/kW) is the unit cost of technology, q represents the cumulative installed capacity, b is the exponent defining the slope of the power function, PR is the progress ratio and LR the learning ratio, (Nemet, 2006). The PR can be assumed as the reduced cost per unit, while the LR is the saved cost for an increase in cumulative output (Nemet, 2006).

The introduced deregulation in market structures is likely to adversely affect whoever bears the risk of production cost volatility. Under competition, it will be difficult for producers to pass on to consumers any increase in cost, which is not related to the whole industry or the specific production method (Kaslow and Pindyck, 1994). However, in Portuguese case, as said earlier the market is still regulated. So this type of uncertainty is not applicable. Nevertheless, it is expected that this market will follow the trend of deregulation, which already happens in a number countries.

4.4. The Real Options evaluation

To start valuing the option, it is necessary to identify the options that are embedded in the project. Given the uncertainties that were defined in the previous section, and the characteristics of the Portuguese electricity market, since it is a regulated market, the one that will most influence the evaluation results is the Initial Capital Cost and technological issues. This type of uncertainty, as said before, can be described by the learning ratios. So, an investor has an opportunity to wait for the reduction of the initial capital cost. Thereby, the investor has an option to defer the investment.

To evaluate this option, the Black and Scholes (1973) model was used (this model was described in section 2.4.2).

To use this model, it is necessary to obtain some data. Most of this data is the same that is used in the NPV evaluation, it is:

- Present value of expected cash flows, S
- Present value of investment outlays, X
- Length of deferral time, t
- Time value of money, r_f
- Volatility of project's returns, σ

As it can be seen, the first four can be obtained in the NPV evaluation which was done before. The last one will be explained further.

4.4.1. Where DCF methods and Real Options are equal and where they are different

The DCF methods use NPV to assess the value of an investment opportunity. Thus, NPV is no more than the difference between the project present value and the required capital expenditures, as shown in equation 14:

$$NPV = S - X \quad (14)$$

When this difference is positive, the investment project should be accepted, otherwise it should be rejected. Curiously, the option value has the same value as the NPV when the project can no longer be deferred. In other words, when the option reaches its expiration date (maturity time). Equation 15 shows that:

$$Call\ Option = \max\{S - X; 0\} \quad (15)$$

When NPV is negative, the company does not undertake the project, so its value is effectively zero, rather than negative. This happens because of the fact that at $t = 0$, σ and r_f do not affect the call option value.

These techniques differ when the decision to invest can be deferred. In this case, two sources of value arise. Firstly, it is always preferable pay later than sooner, all else being equal, because it can be earned the time value of money. Therefore, by investing later, it can be earned the interest on the capital expenditures. That value is the discounted present value of the capital expenditures. In other words, is the present value of the exercise price. Secondly, deferring the decision will turn the uncertainties of the future into certainties of the present. These uncertainties can be measured by assessing probabilities of the future possible project returns. This means that the variance of the project returns will be the percentage gained or lost per year. So, a project return with high variance is riskier than a project with lower variance. Thus, their returns will be either much higher or much lower than average. These new sources of value are the “heart” of RO.

In what follows, three cases will be analysed: the impact of learning curves, the influence of market prices volatility, and a combination of this two.

4.4.2. Case 1 – Learning Curves

The first case that will be analysed under the scope of the Real Options is the effect of the learning curves in this project.

As said in section 4.3, the learning curves range from a minimum of 17% to a maximum of 68%, being 25% the most likely value. If the learning curve can be described by a triangular distribution, the values to calculate the volatility of the project returns can be estimated.

According to Evans et al. (2000), the triangular distribution is a continuous distribution defined on the range $x\ in\ [a, b]$ with probability density function:

$$P(x) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)}\ for\ a \leq x \leq c \\ \frac{2(b-x)}{(b-a)(b-c)} for\ c < x < b \end{cases} \tag{16}$$

and distribution function,

$$D(x) = \begin{cases} \frac{(x-a)^2}{(b-a)(c-a)} \quad for\ a \leq x \leq c \\ 1 - \frac{(b-x)^2}{(b-a)(b-c)} for\ c < x < b \end{cases} \tag{17}$$

where $c \in [a, b]$ is the mode.

Therefore, the value of the volatility of the project's return was obtained applying the model developed by Peng et al. (2010). To implement that model, it is important firstly to consider that there are factors which influence the value of the NPV, like in this case, the learning curve.

So, to carry out the simulations, it is necessary to include all the relevant data, such as investment as a function of the learning curve, revenues, O&M (because of the fact that the O&M are directly related to the investment, means that O&M value will decrease if investment decreases) and set NPV of the project as output of project value in the model, then simulate, getting a variety of different NPV, for each value of investment. Get the standard deviation of NPV according to the following formula, and then get the volatility σ of the project:

$$S_t = \sqrt{\frac{1}{N} \sum_{t=1}^{N} (NPV_t - \overline{NPV})^2} \tag{18}$$

$$\sigma^* = \frac{S}{|\overline{NPV}|} \tag{19}$$

$$\sigma = \frac{\sigma^*}{\sqrt{n}} \tag{20}$$

Where, $\overline{NPV}$ is the expectancy of the project's NPV and n is the duration of the project. In this case, NPV is considered as a factor of volatility. After the calculation of the volatility is carried out, it is now possible to calculate the option value C_t of the project by using Black-Scholes option pricing model.

In this case, the option that will be evaluated is the defer option. So, the decision rule will be:

- Invest, if the traditional NPV is higher than the option value
- Defer, if the traditional NPV is lower than the option value

This calculations where performed using the Monte Carlo simulation implemented in Excel®.

For this case were done 1000000 simulations and were obtained the following results (Table 6) for the NPV with the respective value of the learning curve:

Table 6 – Results of the simulations for case 1

	NPV	Learning Curve
Base Case	11.518.019,61 €	0%
Mean	32.090.599,51 €	37%
$\boldsymbol{S_t}$	6.355.342,55 €	11%
$\boldsymbol{\sigma^*}$	0,1980	---
$\boldsymbol{\sigma}$ (volatility)	0,0396	---

Figure 4 represents the histogram of the case 1 NPV, for each investment value, showing that NPV is triangular distributed.

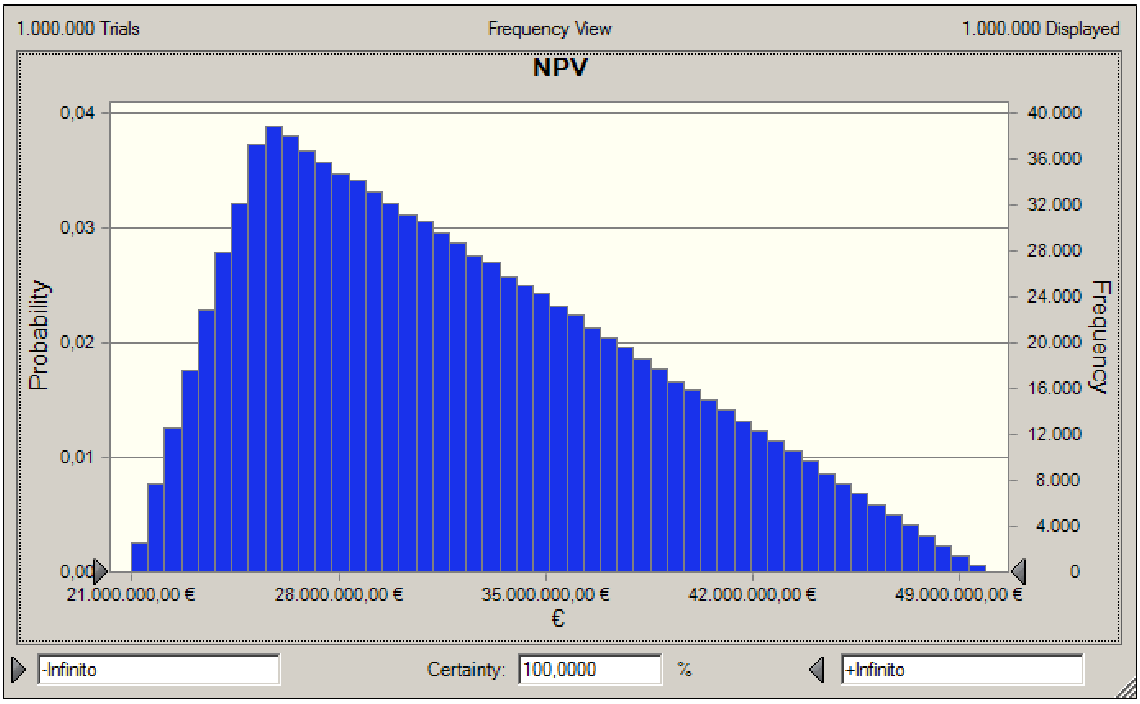

Figure 4 - Case 1 NPV histogram

With the calculation of the volatility, all the necessary data to apply the option pricing model were obtained. The following table shows the real options input data and the option valuation. As said before, the first four variables can be obtained in Annexes A.4 and A.5.

Table 7 – Real Options Input data

Real Options Input Data		
Variables	Project characteristics	Value
S	Present value of expected cash flows	64,65 €
X	Present value of investment outlays	53,13 €
T	Length of deferral time	25
Rf	Time value of money	7,00%
σ	Standard deviation of project returns	5,77%

Values in M€

Table 8 – Option valuation

Black-Scholes Formula	
Option value	51,29 €
d1	1,44367861
d2	1,245678610
Expanded NPV = (option to defer + NPV)	63,11 €

Values in M€

It can be seen that the value of the option is much higher than the NPV of the traditional evaluation. So, by evaluating this project using the ROT it can be obtained a new NPV value. That NPV is called "Expanded NPV" and it contains the value to invest now and the value to defer the investment. Thereby, the decision rule is:

- Invest, if the traditional NPV is higher than the option value
- Defer, if the traditional NPV is lower than the option value

In this case and considering, strictly, the decision rule, the investor should defer the investment and wait to the resolution of the uncertainty. However, since this project has already a positive NPV, it would not be surprisingly that the investor would chose to invest now, earning something rather than loose a good investment opportunity, given that, in the next period, other sources of risk could offset the advantage of deferring the investment.

4.4.3. Case 2 – Market prices

The second case that will be analysed in this work is the effect of the photovoltaic market prices in this investment project.

In fact, this case can not be verified in real projects in Portugal because the photovoltaic market is still regulated, so the price that producers sell their energy is stipulated by government laws. However, the objective of this case is, mostly, to give indications about what would be the investment decision if the sell price was defined by the market.

To calculate the uncertainty of the market prices, it was necessary to obtain the historical data of the selling price of photovoltaic energy. To give more realistic results, that data should be hourly based, because of the fact that prices differ in peak hours and off-peak hours. In peak hours the price is relatively higher whereas in off peak hours the price is lower. The peak hours usually occur during the day while the off-peak hours occur mainly during the night. So, the photovoltaic selling price is mostly affected by the peak hour price since this type of RES can only produce during the day. However, since it was extremely difficult to obtain the data hourly based, the average monthly prices were used. That data was obtained in the *Operador del Mercado Ibérico de Energía* (OMEL) database from July of 2007 to June of 2011. This data was described by a lognormal distribution.

According to Balakrishnan and Chen (1999), the lognormal distribution is a continuous distribution in which the logarithm of a variable has a normal distribution. It is a general case of Gibrat's distribution, to which the log normal distribution reduces with standard deviation (S) equal to 1 and mean (M) equal to =. A lognormal distribution results if the variable is the product of a large number of independent, identically-distributed variables in the same way that a normal distribution results if the variable is the sum of a large number of independent, identically-distributed variables. For example, in finance, the variable could represent the compound return from a sequence of many trades (each expressed as its return + 1); or a long-term discount factor can be derived from the product of short-term discount factors.

The probability density and cumulative distribution functions for the log normal distribution are:

$$P(x) = \frac{1}{S\sqrt{2\pi}x} e^{-(\ln x - M)^2/(2S^2)} \tag{21}$$

$$D(x) = \frac{1}{2}\left[1 + erf\left(\frac{\ln x - M}{S\sqrt{2}}\right)\right] \tag{22}$$

where $erf(x)$ is the erf function.

The volatility was obtained, and the calculation of the option value was done following the same method as in case 1.

In this case, the option that will be evaluate is the defer option. So, the decision rule will be:

- Invest, if the traditional NPV is higher than the option value
- Defer, if the traditional NPV is lower than the option value

This calculations where performed using the Monte Carlo simulation implemented in Excel®.

For this case, 1000000 simulations were made and the results presented in Table 9 for the NPV, with the respective value of the learning curve, were obtained:

Table 9 – Results of the simulations for case 2

	NPV	Revenues
Base Case	11.518.019,61 €	5760000,00 €
Mean	-45.378.941,57 €	877642,33 €
$\boldsymbol{S_t}$	3.340.315,60 €	286634,21 €
$\boldsymbol{\sigma}^*$	0,0736	---
$\boldsymbol{\sigma}$ (volatility)	0,0147	---

Figure 5 represents the histogram of the case 2 NPV, for each investment value, showing that NPV is log normal distributed.

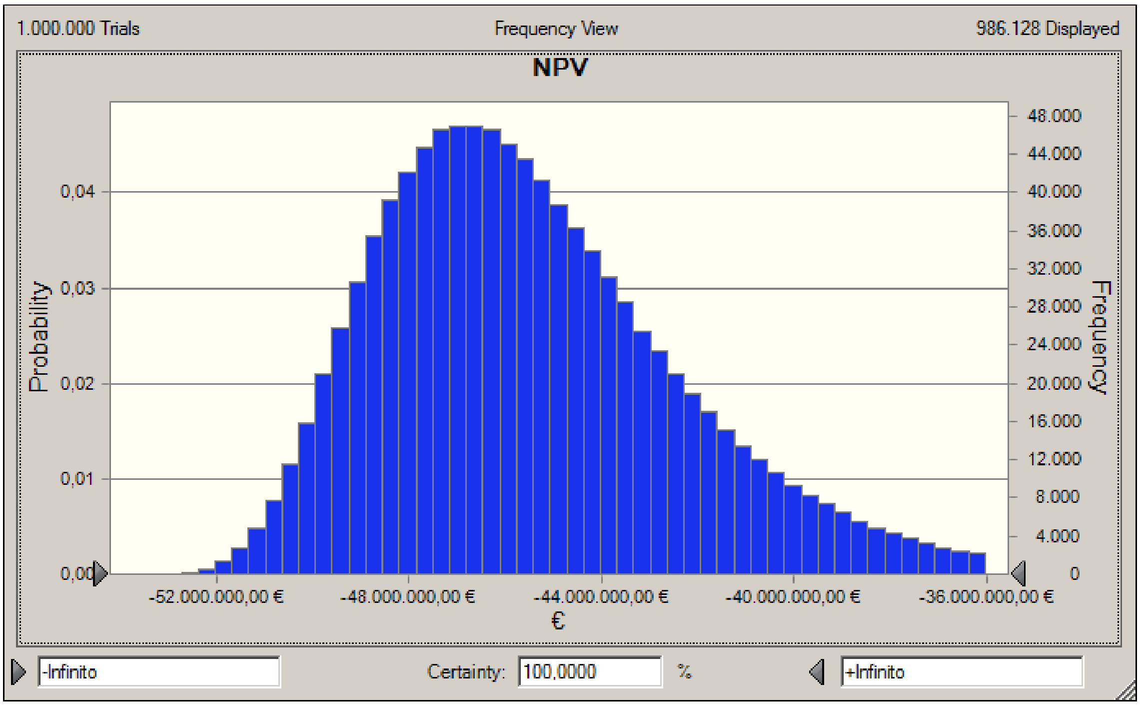

Figure 5 - Case 2 NPV histogram

With the calculation of the volatility, all the necessary data to apply the option pricing model were obtained. The following table shows the real options input data and the option valuation. As mentioned before, the first four variables can be obtained in Annexes A.4 and A.5.

Table 10 – Real Options Input data

Real Options Input Data		
Variables	Project characteristics	Value
S	Present value of expected cash flows	64,65 €
X	Present value of investment outlays	53,13 €
T	Length of deferral time	25
Rf	Time value of money	7,00%
σ	Standard deviation of project returns	1,47%

Values in M€

Table 11 – Option valuation

Black-Scholes Formula	
Option value	55,41 €
d1	3,65914952
d2	3,585649520
Expanded NPV = (option to defer + NPV)	66,93 €

Values in M€

In this case and considering the decision rule, the investor should defer the investment and wait to the resolution of the uncertainty, as one would expect. The price of the electricity has a big influence in the financial results of photovoltaic investment projects.

4.4.4. Case 3 – Learning Curves and Market Prices

The third case that will be analysed in this work is the combination of the two previous cases.

This case is important to give indications about what would be the investment decision if the value of the investment decreases but the price of the energy is defined by the market.

The volatility was obtained, and the calculation of the option value was done with the same method as in the two previous cases.

In this case, the option that will be evaluate is the defer option. So, the decision rule will be the same as in the previous case.

This calculations where performed using the Monte Carlo simulation implemented in Excel®.

As previously, 1000000 simulations were done and the following results (Table 12) for the NPV, with the respective value of the learning curve, were obtained:

Table 12 – Results of the simulations for case 3

	NPV	Revenues	Learning Curve
Base Case	11.518.019,61 €	5760000,00 €	0%
Mean	-24.940.443,06 €	881615,65 €	37%
S_t	5.952.057,89 €	288096,10 €	11%
σ^*	0,3268	---	---
σ (volatility)	0,0568	---	---

Figure 6 shows the contribution of the learning curve and the average monthly prices to the deviation of the NPV. It can be seen that the learning curve has a contribution of 80,1% and the monthly prices 19,9 %. So the learning curve, namely the investment value, has an important influence in the results of photovoltaic projects.

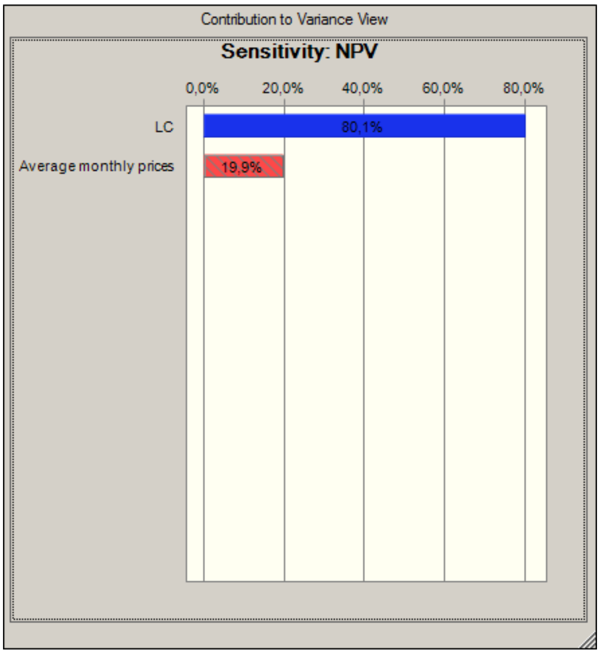

Figure 6 – Sensitivity analysis of the NPV, case 3

With the calculation of the volatility, all the necessary data to apply the option pricing model were obtained. The following table shows the real options input data and the option valuation.

Table 13 – Real Options Input data

Real Options Input Data		
Variables	Project characteristics	Value
S	Present value of expected cash flows	64,65 €
X	Present value of investment outlays	53,13 €
T	Length of deferral time	25
Rf	Time value of money	7,00%
σ	Standard deviation of project returns	5,68%

Values in M€

Table 14 – Option valuation

Black-Scholes Formula	
Option value	48,32 €
d1	1,0794872
d2	0,795487200
Expanded NPV = (option to defer + NPV)	59,84 €

Values in M€

In this case and considering the decision rule, the investor should defer the investment and wait to the resolution of the uncertainty.

5. Conclusions and further work

The traditional DCF methods may fail in the evaluation of projects that are characterized by uncertainty and high financial risks. Those methods do not take into account the possibility of variations on cash flows, according to market changes or sensitivity of investors. Those changes are extremely important. A project that seems to be a good one can be turned into a bad one, only by the uprising of the prices of raw materials, or a sudden crisis of the financial markets. Sometimes, traditional methods provide misleading information and that is the major drawback of those methods. Although, the RO approach does not give the answer to all the issues in the project evaluation, it can provide more accurate information to the decision maker, giving the possibility of better decisions. Curiously, by incorporating risk in the analysis, this is done with less risk. In other words, the results obtained are more precise. Nevertheless, RO theory is often difficult to apply in practice. In fact, uncertainties are extremely difficult to model with precision and require sophisticated techniques, like simulation tools. Also, the equations that are used in RO require a great mathematical knowledge and can be arduous to apply. Even the line of thought that should be followed in order to use RO theory is different from the one that is needed in DCF methods. This rupture of thinking is as difficult as applying the methodology. In spite of all that, not only on energy sector, but also in major public investments, like airports, seaports or railways, ROT can be an important tool to better evaluate (or assess) the value of investments.

As seen in the literature review, this theory has been used in all ranges of the energy sector, from generation to evaluation of policies. This increase reveals that the interested parties in the energy sector are now aware of the limitations of the traditional techniques, given the potential of the real options theory. The RES sector is no exception and a few studies using the Real Options Theory appeared recently in the literature, although this particular literature is still limited.

RES projects have particular characteristics that imply selecting methods capable to assess their correct value taking into account these particularities. Namely, these projects have high initial costs, low marginal costs, high financial risk and uncertainties. These uncertainties are caused by their natural sources variability, the possible changes in the support schemes and by their learning curves exhibiting very steep slopes. These project’s interest is also indirectly affected by the fossil fuel prices and consequently by the prices of the electricity and, as so, the markets uncertainty also affects these kinds of projects.

Taking into account the exposed reasons, Real Options Theory seems to be an evaluation method that can provide a more realistic value of a RES investment project. However, there seems to exist a lack of application of this technique to this field and, as so, the authors frequently resource to the simulation of the application. Real Options proved that can produce better results than other methods. To the author’s best knowledge this technique was not frequently applied to other RES, beyond wind power and hydropower.

Regarding the case of a photovoltaic investment, its evaluation under the ROT provides some interesting conclusions. The mere fact that this technology has learning curves with very steep slopes makes a project that is not profitable in a given year, to become profitable one year later. Therefore, the evaluations that can be done to similar projects must consider those issues.

Although, the evaluation undertaken in this work does not use a detailed financial investment data, it can be regarded as being done for the best case. The major conclusion is that, in all cases analyzed, the investor should wait for the resolution of the uncertainty and then evaluate the project again.

Also, it was found that the impact of the learning curves in the financial results is bigger than the impact of the market prices. However, both of these issues are extremely important to not be considered in the evaluation of projects like this one.

Another factor that can not be overlooked is the fact that the market prices are not hourly based, and according to authors conviction the results would be different.

Although the decision given by ROT was to defer the investment, this does not, necessarily, mean that the investor would defer it. In fact, as the NPV of the base case is positive, if the investor defers the investment, he might lose the opportunity of generate a profit in the present. What the application of ROT allows is the investor to know what the postponing of the investment is worthing.

Another conclusion that can be drawn refers to the fact that this technique can provide better knowledge of the potential and better evaluate these new technologies.

An opportunity of investment in this area has been growing in Portugal, so if investors have more accurate methods to evaluate those opportunities they may be more receptive to investment and thus help in the revitalization of the Portuguese economy. Real Options theory is one of those accurate methods.

5.1. Further work

Despite the great theoretical advantages of RO approach that were pointed out, to the author's best knowledge, this approach has not been much applied (or used in real situations). So, an important step in would be the development of a software that could turn RO more "user friendly". The training of managers in order to raise awareness of the potential of this approach is a great way to the spread of RO. This technique can be applied to almost all types of investments in different sectors. However, the absence of applications has been an obstacle to their use.

Although the photovoltaic market, in Portugal, is still regulated, it is important to predict what would happen when the deregulation occurs. So, the development of a Real Options model to apply in a deregulated market will be a very important step in. In that case, other types of uncertainty will be present and therefore it will be necessary to compute those uncertainties. Thus, some interesting insights of the markets will be provided.

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Annexes

A.1 The development of the Black and Scholes (1973) option pricing model

The Black and Scholes model is based on the designing of a portfolio composed of an action (V) into m options (C), with m chosen so that the portfolio is risk free:

$$\Pi = V + mC \tag{23}$$

Because the portfolio is risk free, the instantaneous will be the rate r in a similar manner to a fixed income security without credit risk:

$$d\Pi = r\Pi dt \tag{24}$$

For this reason is that the underlying asset (V) varies in time governed by the stochastic process called Geometric Brownian Motion (GBM):

$$\frac{dV}{V} = \mu dt + v dz \tag{25}$$

The option (C) is a function of V and time (t) and has as parameters: r, the volatility of V (v) the exercise price of the option (K) and the exercise date (T).

$$C = f(V, t; r, v, K, T) \tag{26}$$

Applying the Itô's lemma it is possible to obtain the stochastic differential of the option spot price:

$$dC = \frac{\partial f}{\partial V} dV + \frac{\partial f}{\partial t} dt + \frac{1}{2}\frac{\partial^2 f}{\partial V^2} dV^2 \tag{27}$$

With $\Pi = x + mw$, it has also

$$d\Pi = dV + mdC \tag{28}$$

If the two expressions equated to $d\Pi$, replacing the result found for dC by Itô's lemma and it is considered $m = \partial f / \partial V$.

$$\frac{\partial C}{\partial t} + \frac{1}{2} v^2 V^2 \frac{\partial^2 C}{\partial V^2} + rV \frac{\partial C}{\partial V} - rC = 0 \tag{29}$$

Considering the boundary conditions at maturity $C(V) = V - K$, if $V \geq K$ and $C\,(V) = 0$ if $V < K$ and that $C = 0$ when $V = 0$, Black and Scholes achieved, by replacing the variables, convert the partial differential equation in the heat formula, which has a standard solution, and applying the Fourier theorem, obtained the following closed formula for pricing European call options:

$$C(V,t) = VN(d_1) - Ke^{-r(T-t)}N(d_2) \tag{30}$$

Subject to,

$$d_1 = \frac{\ln\left(\frac{V}{K}\right) + \left(r + \frac{v^2}{2}\right)(T-t)}{v\sqrt{(T-t)}} \tag{31}$$

$$d_2 = d_1 - v\sqrt{(T-t)} \tag{32}$$

Where,

- $N(.)$ is the cumulative distribution function
- $T - t$ is the time to maturity
- V is the spot price
- K is the strike price
- r is the risk free rate
- v is the volatility of the returns of the underlying asset

A.2 Historical perspective of the reviewed studies applying Real Options Theory to the energy sector

Authors	Year	Application
Siegel et al.	1987	Oil industry
Paddock et al.	1988	Oil industry
Ekern	1988	Oil industry
Dixit and Pindyck	1994	Book: case studies in energy sector
Trigeorgis	1996	Book: case studies in energy sector
Amram and Kulatilaka	1999	Book: case studies in energy sector
Felder	1995	Power generation
Ghosh and Ramesh	1997	Energy market
Hsu	1998	Power generation
Frayer and Uludere	2001	Power generation
Deng et al.	2001	Energy market
Armstrong et al.	2004	Oil industry
Moreira et al.	2004	Power generation
Hlouskova	2005	Power generation
Madlener et al.	2005	Power generation
Laurikka and Koljonen	2006	Impact of emission policy
van Benthem et al.	2006	Power generation
Chorn and Shokhor	2006	Policies study
Blyth and Yang	2006	Impact of climate change policy
Deng and Xia	2006	Energy market
Marreco and Carpio	2006	Power generation
Botterud and Korpas	2007	Energy market
Prelipcean and Boscoianu	2008	Energy market
Abadie	2009	Energy market
Bonis et al.	2009	Energy market
Fuss et al.	2009	Impact of climate change policy
Uçal and Kahraman	2009	Oil industry
Fan and Zhu	2010	Oil industry
Fleten and Näsäkkälä	2010	Power generation

A.3 Historical perspective of the reviewed studies applying Real Options Theory to the RES

Authors	Year	Resource type	Area of application
Venetsanos et al.	2002	Wind Energy	Power generation
Davis and Owens	2003	Renewable energy technologies	R&D Program
Yu et al.	2006	Wind Energy	Policy evaluation
Kjarland	2007	Hydropower	Policy evaluation
Siddiqui	2007	Renewable energy	R&D investments
Bockman et al.	2008	Hydropower	Power generation
Kumbaroğlu et al.	2008	Renewable energy technologies	Policy evaluation
Muñoz et al.	2009	Wind Energy	Power generation
Siddiqui and Fleten	2010	Renewable energy technologies	Policy evaluation
Lee and Shih	2010	Renewable energy	Policy evaluation
Martínez-Ceseña and Mutale	2011	Hydropower	Power generation

A.4 Calculations of the financial data and cash flows, part 1

Operating Projections	Years								
	0	1	2	3	4	5	6	7	8
1. Revenues		5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00
2. O&M		212520,00	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00
Operating profit (1-2)		5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00
Investment	53.130.000,00 €								
Discount factor (7%)	1,00	0,93	0,87	0,82	0,76	0,71	0,67	0,62	0,58

PV	53.130.000,00 €	5.184.560,75 €	4.845.383,88 €	4.528.396,15 €	4.232.145,93 €	3.955.276,57 €	3.696.520,16 €	3.454.691,74 €	3.228.683,87 €

Operating Projections	Years								
	9	10	11	12	13	14	15	16	17
1. Revenues	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00
2. O&M	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00
Operating profit (1-2)	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00
Investment									
Discount factor (7%)	0,54	0,51	0,48	0,44	0,41	0,39	0,36	0,34	0,32
PV	3.017.461,56 €	2.820.057,53 €	2.635.567,79 €	2.463.147,46 €	2.302.006,98 €	2.151.408,39 €	2.010.662,05 €	1.879.123,41 €	1.756.190,10 €

A.5 Calculations of the financial data and cash flows, part 2

Operating Projections	Years							
	18	19	20	21	22	23	24	25
1. Revenues	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00	5760000,00
2. O&M	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00	212520,00
Operating profit (1-2)	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00	5547480,00
Investment								
Discount factor (7%)	0,30	0,28	0,26	0,24	0,23	0,21	0,20	0,18
PV	1.641.299,16 €	1.533.924,45 €	1.433.574,25 €	1.339.789,02 €	1.252.139,27 €	1.170.223,62 €	1.093.666,93 €	1.022.118,63 €

A.6 Photovoltaic selling prices from July 2007 to June 2011

Month	Average monthly price (€/KWh)	Month	Average monthly price (€/KWh)
Jul-07	0,046	Jul-09	0,036
Aug-07	0,044	Aug-09	0,035
Sep-07	0,044	Sep-09	0,036
Oct-07	0,046	Oct-09	0,036
Nov-07	0,059	Nov-09	0,033
Dec-07	0,074	Dec-09	0,030
Jan-08	0,074	Jan-10	0,028
Feb-08	0,073	Feb-10	0,028
Mar-08	0,065	Mar-10	0,020
Apr-08	0,062	Apr-10	0,026
May-08	0,062	May-10	0,037
Jun-08	0,065	Jun-10	0,041
Jul-08	0,073	Jul-10	0,044
Aug-08	0,072	Aug-10	0,044
Sep-08	0,076	Sep-10	0,048
Oct-08	0,076	Oct-10	0,044
Nov-08	0,077	Nov-10	0,042
Dec-08	0,064	Dec-10	0,045
Jan-09	0,051	Jan-11	0,041
Feb-09	0,040	Feb-11	0,048
Mar-09	0,038	Mar-11	0,047
Apr-09	0,038	Apr-11	0,047
May-09	0,038	May-11	0,049
Jun-09	0,038	Jun-11	0,051